NATIVE VS. EXOTIC WOODY VEGETATION RECOVERY FOLLOWING GOAT REMOVAL IN THE EASTERN COASTAL LOWLANDS OF HAWAII VOLCANOES NATIONAL PARK

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INTRODUCTION

Goats (Capra hircus L.) were originally introduced to the island of Hawai'i by Captain James Cook in 1778 and later by Captain George Vancouver in 1792 (Tomich 1969) as a source of meat for the crews of returning ships. Provided with a preferred semi-arid climate, the absence of natural predators, and protection from human consumption by royal decrees (kapu) (Tomich 1969), the goats multiplied rapidly and reverted to a feral state. They were already quite abundant and widespread by 1850 (Marques 1906). Goat round-ups held twice a year during the early 20th century in the Kealokomo-Pānau region by the area's families yielded thousands of the animals for food and trade (Le Hong, pers. comm.). By 1931, 75,000 goats were said to roam the island of Hawai'i (Bryan 1931), and Wingate (in Morris 1967), in describing a trip from Hilina Pali to Pepeiau, noted that "upwards of 2,000 goats were seen and close observation revealed not a single tree less than 15 to 20 years old."

The indiscriminate and voracious eating habits of the goats present a significant threat to species which have not evolved defenses against browsing animals. Although browse is preferred, herbs are also consumed including those unpalatable to other herbivores (Roots 1976). Judd (1922) reported "thousands of acres robbed of valuable forage grasses...undergrowth of ferns, bushes and herbaceous plants...is being entirely consumed or destroyed by the goats. The trees which form the complement in the scheme of water conservation are being barked and killed by this voracious pest."

Through goat stomach contents studies, Yocum (1967) on Maui and Morris (1969) on Hawai'i found that, when available, the animals prefer native over exotic browse. Due to their eating habits the regeneration of native plants has been hindered and the food sources of the native fauna, especially native birds, have declined (Baker & Reeser 1972). Thus, goats must be considered a significant agent in the destruction of both native Hawaiian flora and fauna.

The Kalapana Extension was annexed to Hawaii Volcanoes National Park (HAVO) in 1938. At that time a goat eradication program in the form of organized goat drives was implemented in the Hilina Pali-Ka'ū region such that by 1941 more than 7000 goats had been removed (Geerdes 1964). While World War II brought a temporary end to the drives, after the war the program was reinstated. Through various short- and and long-term contracts goats have been eradicated steadily through the efforts of National Park Service (NPS) employees.

By 1970, more than 30,000 animals had been removed. However, 14,000 goats were estimated to be in the Park still. Beginning in 1970, the combined efforts of both private citizens and the National Park Service, working together under a more organized goat eradication program, resulted in a significant reduction of the remaining goat population (Baker & Reeser 1972). By 1974, almost all goats had been eliminated from the eastern coastal region of HAVO (Roberts, pers. comm.). This large-scale goat eradication program provided the opportunity to study the regeneration of woody vegetation in the eastern coastal lowlands of HAVO in the absence of herbivore browsing and grazing pressure, as well as determine the community relationships between native and exotic woody species.

STUDY AREA DESCRIPTION

The eastern Kalapana Extension lies along the downslope of the volcanically active East Rift of Kīlauea (Fig. 1). Thus, there are numerous young lava flows in the area. The substrate in most of the study area is smooth pāhoehoe lava with many cracks. However, in some places the pāhoehoe may be upheaved and blocky or, upon flowing downhill, may have turned into sharp rubbly 'a'ā. Very little top soil is found on any of these substrates.

Climatically, the eastern Kalapana Extension has a Mediterranean-type rainfall regime with wet winters and dry summers. Rainfall is approximately 190 cm per year following a gradient from sea level to 120 m from east to west (Taliaferro 1959). Thus, at each elevation there is a northeast to southwest decrease in precipitation reflecting the shift from windward to leeward exposure. The average annual temperature is 22.5°C (Jones 1942).

The specific study area extends from sea level at the extreme eastern Park boundary to 60 m elevation inland, then 14 km west along the Chain of Craters Road where the elevation ranges from 120 m to 500 m (See shaded area, Fig. 1). This area encompasses the coastal lowland woody vegetation zone. Above is transition forest and below is arid semi-desert.

The study area has been free of goats for approximately six years above the Hōlei Pali and for approximately 15 years in the lower coastal portion due to road construction activity in 1965 (Roberts, pers. comm.).

METHODS

The analysis of woody communities was divided into two types--scrub and forest. Sites with woody vegetation generally less than 2 m tall were defined as scrub communities; those sites consisting of woody vegetation of all sizes including greater than 2 m tall were defined as forest communities. In both types a site was used if at least 25% of the area observed was covered with woody vegetation.

The scrub sites were analyzed using a combination of relevés, point frequency method, line intercept method, and crown diameter measurement of a selected species (Mueller-Dombois & Ellenberg 1974). In addition, all seedlings within a site were counted and divided into three classes according to height (in cm) (Fig. 2).

The forest sites were analyzed using structural analysis and relevés. Stand structure is the "numerical distribution of differently sized individuals within each tree species of a given stand" (Mueller-Dombois & Ellenberg 1974). A graphic description of this method is shown in Figure 3.

A total of 42 sites were analyzed--20 scrub and 22 forest. Representative as well as anomalous communities within the eastern coastal lowlands of HAVO were included. Ten sites--five forest and five scrub--have been permanently tagged for future monitoring.

RESULTS

The field work for this study was finished just recently; therefore, not all statistical analyses have been completed. However, there are certain consistent trends within the communities.

In the scrub sites the mat-forming native shrub 'ūlei (Osteomeles anthyllidifolia (Lindl.)) appears to be displacing exotic grasses (e.g., Andropogon spp., Rhynchelytrum repens (Willd.) C. E. Hubb.). The mats lie close to the ground and afford sufficient space and exposure to light between its branches for plant germination to take place; however, little herbaceous growth has been observed within the mats while herbaceous vegetation is dense at the perimeters. In addition, although 'ūlei individuals have been observed to flower and set

fruit abundantly, relatively few seedlings of the species have been observed (Tables 1 & 2). Regeneration is almost exclusively by shoot expansion.

In the forest sites four consistent trends have been observed. The most rapidly regenerating native tree is alahe'e (Canthium odoratum (Forst. f.) Seem.). It is found in more communities than any other woody native, usually in association with 'ākia (Wikstroemia phillyreifolia (Gray)) at lower elevations and lama (Diospyros ferrea (Willd.) Bakh.) at higher as well as lower elevations. Far more alahe'e seedlings have been recorded than any other woody species in the study area (Table 1).

Kukui-lantana (Aleurites moluccana (L.) Willd. - Lantana camara L.) communities are found along Hōlei Pali. From field observations it appears that the kukui is displacing the lantana. The kukui has been observed commonly growing as seedlings within lantana thickets. Once tall enough it appears to shade out the lantana in its immediate vicinity. In large groves of kukui trees all but remnant lantana are absent; however, lantana thickets still persist in the sunny perimeters.

As with 'ūlei, few "true" seedlings of lantana have been recorded (Tables 1 & 2). Most new growth have been from root and shoot sprouts. One of the imported biological controls for lantana, Thecla bazochii, has frequently been observed on lantana individuals. In the larval stage this moth feeds on flowers and bores through seeds, apparently reducing the number of viable seeds.

Finally, in the 'a'ali'i-'ōhi'a (Dodonaea viscosa Jacq. - Metrosideros polymorpha Gaud.) community, 'a'ali'i is regenerating in high density except for those areas into which molasses-grass (Melinis minutiflora Beauv.) is invading. The mats formed by this exotic allow neither sufficient space nor light for seed germination. Thus, 'a'ali'i seedling counts in these areas are very low.

CONCLUSION

According to residents in the Kalapana area and to Kalapana Park Ranger Kaipo Roberts, there have been increases in the cover of woody plants--both native and exotic--since goat grazing and browsing pressure have been eliminated. The final data analyses have yet to be performed but from my field work it can be said that, in most forest communities, the native woody species are dominant. However, exotic species--both herbaceous and woody--are persisting, usually at a subordinate level. Therefore, although the woody natives are apparently recovering as dominants, it is possible that community structure will not return to the predisturbed state but, rather, emerge with greater species richness.

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TABLE 1. Forest sites seedlings. Mean counts per 1000 m^2 according to number of sites in which a species was found (a), and total number of sites analyzed - 22 (b).

Species	*	$\bar{X}$/1000 m^2 in Sites Found[a]			$\bar{X}$/1000 m^2 for All Sites[b]		
		Heights of Seedlings (in cm)					
		0-20	20-40	40-60	0-20	20-40	40-60
Canthium odoratum	14	755.0	357.0	135.6	480.5	227.2	86.3
Wikstroemia phillyreifolia	8	191.5	141.3	65.1	69.6	51.4	23.7
Diospyros ferrea	9	208.0	51.2	30.1	85.1	21.0	12.3
Dodonaea viscosa	7	270.0	176.3	135.7	86.0	56.1	43.2
Osteomeles anthyllidifolia	3	149.7	21.7	17.7	20.4	3.0	2.4
Aleurites moluccana	5	182.2	245.6	218.8	41.4	55.8	49.7
Metrosideros polymorpha	1	10.0	4.0	2.0	0.5	0.2	0.1
Schinus terebinthifolius	4	103.3	50.8	16.1	18.8	9.2	3.0
Psidium guajava	12	127.7	42.3	25.9	69.6	23.1	14.1
Psidium cattleianum	4	218.3	130.8	61.3	39.7	23.8	11.1
Lantana + camara	17	106.5	86.2	45.2	82.3	66.6	34.9
Indigofera suffruticosa	4	15.0	8.0	3.0	2.8	1.5	0.6
Leucaena latisiliqua	1	226.0	306.0	116.0	10.3	13.9	5.3
Eugenia cumini	2	216.5	57.5	16.5	19.7	5.2	1.5
Cassia surattensis	2	161.0	105.5	70.0	14.6	9.6	6.4
Styphelia tameiameiae	1	13.0	46.0	46.0	0.6	2.1	2.1

* Number of sites in which species was found.
a Total number of individuals divided by number of sites in which found.
b Total number of individuals divided by number of sites analyzed (22).

TABLE 2. Scrub site seedlings. Mean counts per 1000 m^2 according to number of sites in which a species was found (a), and total number of sites analyzed - 20 (b).

Species	*	X/1000 m^2 in Sites Found[a]			X/1000 m^2 for All Sites[b]		
		Heights of Seedlings (in cm)					
		0-20	20-40	40-60	0-20	20-40	40-60
Canthium odoratum	11	14.4	5.2	2.0	7.9	2.9	1.1
Wikstroemia phillyreifolia	10	28.8	13.5	6.0	14.4	6.8	3.0
Diospyros ferrea	1	7.0	3.0	1.0	0.4	0.2	0.1
Dodonaea viscosa	8	56.0	53.1	39.5	22.4	21.3	15.8
Osteomeles anthyllidifolia	9	1.9	0.0	0.0	0.9	0.0	0.0
Aleurites moluccana	0	0.0	0.0	0.0	0.0	0.0	0.0
Metrosideros polymorpha	0	0.0	0.0	0.0	0.0	0.0	0.0
Schinus terebinthifolius	6	7.9	4.5	3.2	2.3	1.4	1.0
Psidium guajava	8	6.1	4.5	3.0	2.3	1.8	1.8
Psidium cattleianum	0	0.0	0.0	0.0	0.0	0.0	0.0
Lantana + camara	18	17.3	10.2	12.0	7.3	9.2	10.0
Indigofera suffruticosa	3	41.0	17.3	12.3	6.2	2.6	1.9
Leucaena latisiliqua	0	0.0	0.0	0.0	0.0	0.0	0.0
Eugenia cumini	1	0.0	8.0	5.0	0.0	0.4	0.3
Cassia surattensis	0	0.0	0.0	0.0	0.0	0.0	0.0
Styphelia tameiameiae	0	0.0	0.0	0.0	0.0	0.0	0.0

* Number of sites in which species was found.
a Total number of individuals divided by number of sites in which found.
b Total number of individuals divided by number of sites analyzed (20).
\+ Majority of Lantana "seedlings" were in fact root and shoot sprouts.

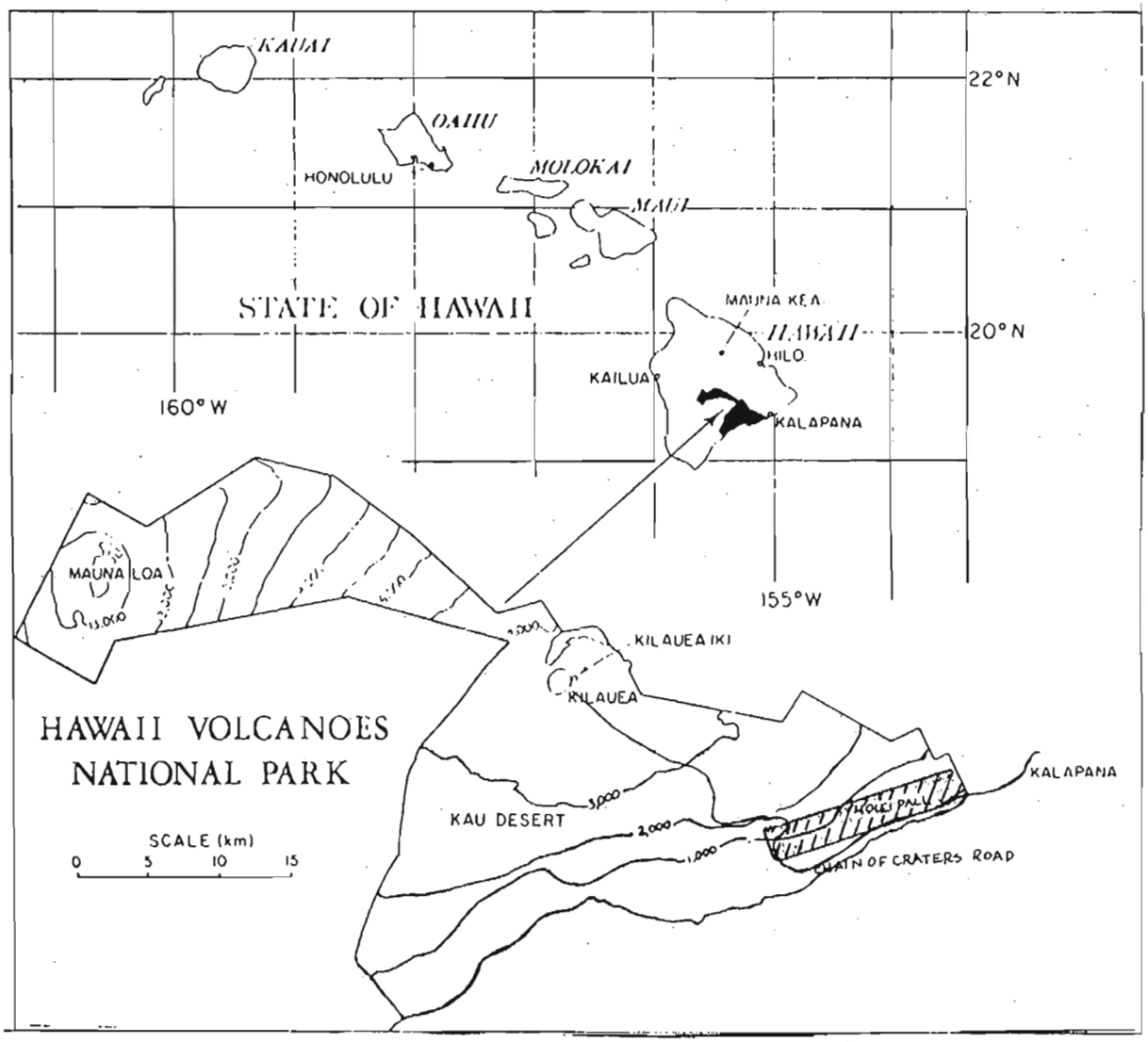
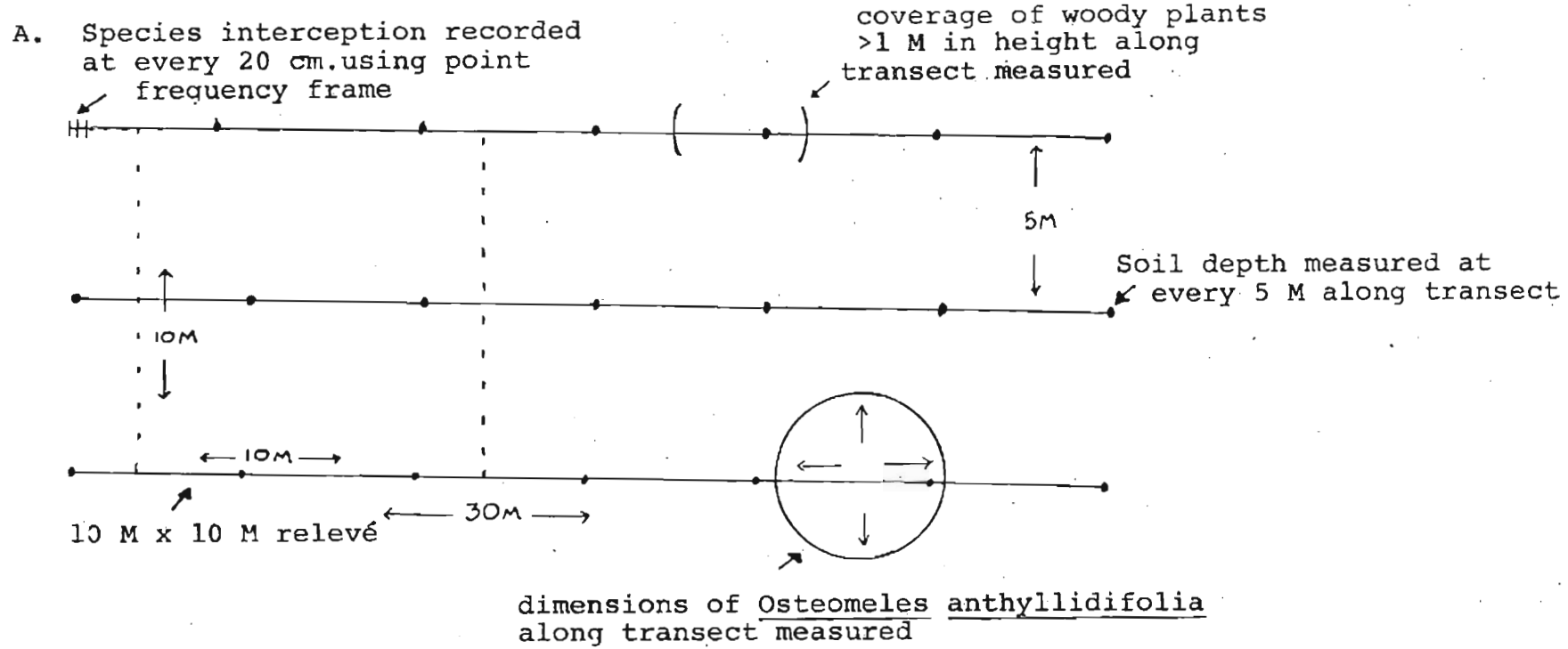


FIGURE 1. Map of the major Hawaiian Islands showing the location of the study area (hatched) in Hawaii Volcanoes National Park, island of Hawai'i.



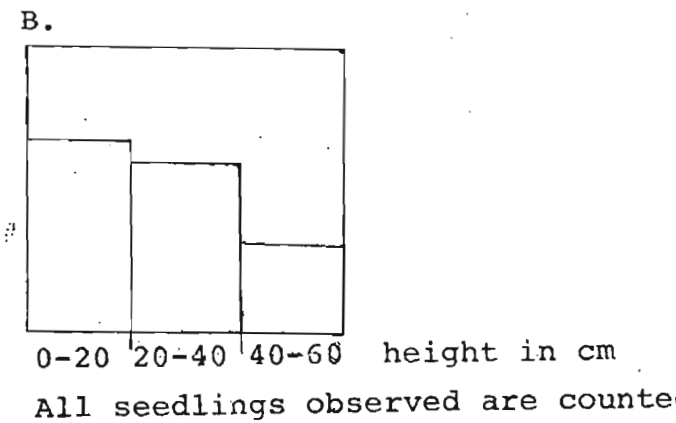
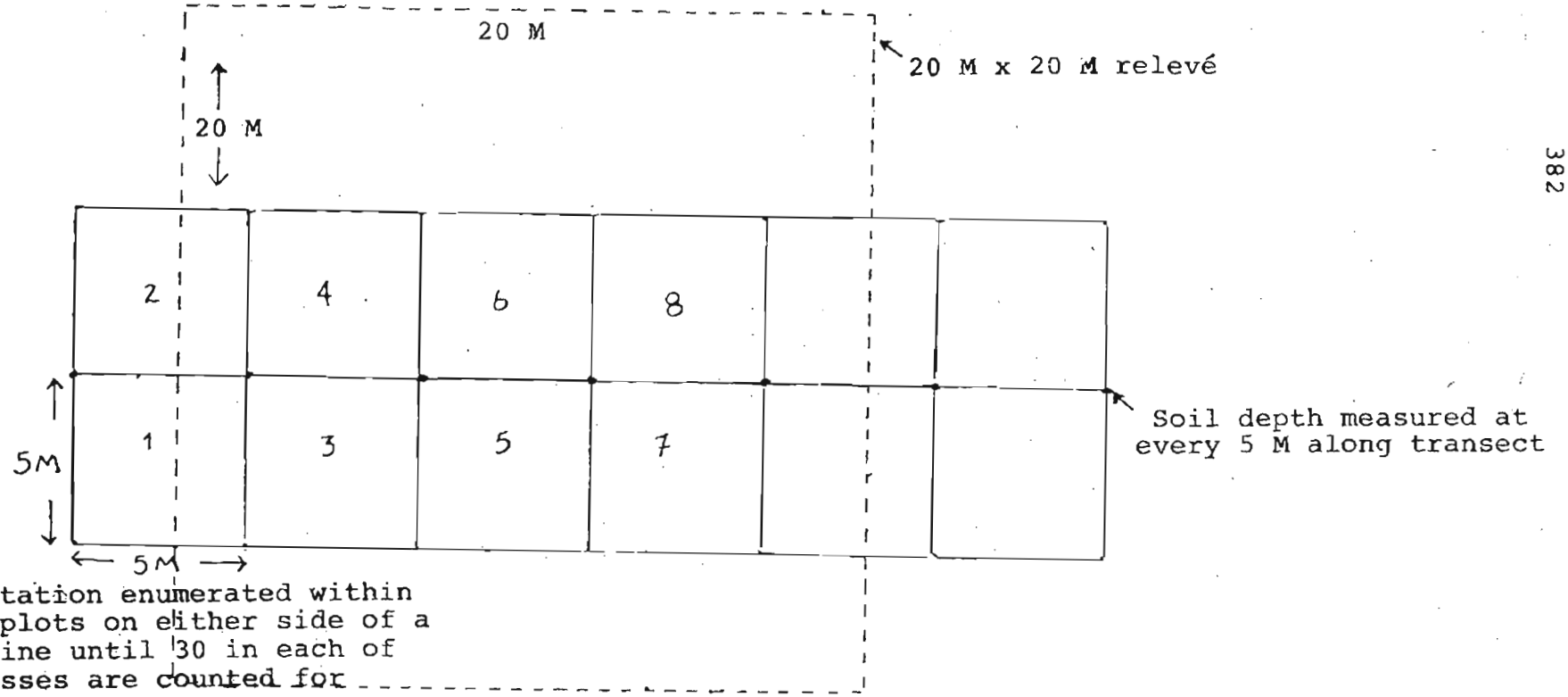


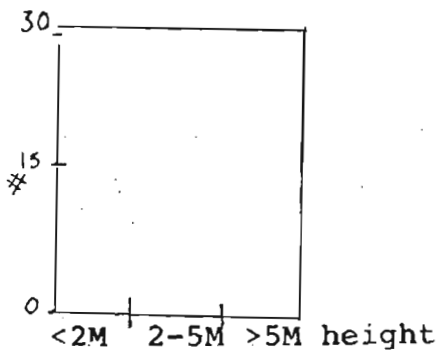
FIGURE 2. Scrub site transect measurements. A. Transect dimensions, relevé dimensions, species recording, soil depth measurement, woody species measurement. B. Seedling height classes.

A.



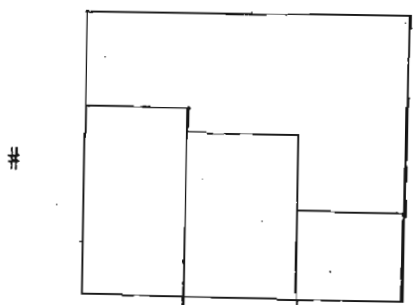
Woody vegetation enumerated within 5 M x 5 M plots on either side of a transect line until 30 in each of 3 size classes are counted for dominant(s)

B.



Up to 30 individuals are counted in each size class for each dominant species

C.



All seedlings observed are counted

FIGURE 3. Forest site plot measurements. A. Stand structural plot dimensions in which heights and diameters are recorded, relevé dimensions, soil depth measurement. B. Sapling and tree measurement height classes. C. Seedling height classes.